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MECHANICAL CHARACTERIZATION OF MODERATELY WARM ASPHALT BINDER COURSE MIXES USING RUBBER-MODIFIED AND CONVENTIONAL BITUMENS

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Abstract

This study summarizes a multi-phase laboratory program evaluating moderately warm asphalt mixtures produced with conventional B 50/70 bitumen and RMB 45/80-55 rubber-modified binders. AC 16 binder course mixtures were tested across a 130–180°C production temperature range using several warm-mix additives. Key performance indicators – including stiffness, rutting resistance, moisture sensitivity, and compactability – were measured according to MSZ EN 12697 standards. Results show that appropriately selected warm-mix additives maintain mechanical performance at reduced temperatures, with rubber-modified mixtures exhibiting equal or improved behavior compared to hot-mix references. Industrial-scale aggregate blends validated the laboratory findings, confirming that WMA2 and WMA3 technologies enable reliable production at 130°C. Overall, the outcomes demonstrate that moderately warm rubber-modified asphalt mixtures provide a technically viable and energy-efficient alternative to conventional hot-mix asphalts.

Keywords: rubber bitumen, warm mix asphalt additive, mechanical properties

1 Introduction

The production of asphalt mixtures for road construction has traditionally relied on high-temperature processes. Conventional Hot Mix Asphalt (HMA) is typically manufactured at binder temperatures between 160–180°C in order to sufficiently reduce binder viscosity and ensure adequate aggregate coating and compactability [1, 2]. However, such elevated production temperatures result in significant energy consumption, increased greenhouse gas emissions, and accelerated oxidative aging of the binder [3]. In response to these environmental and technological challenges, Warm Mix Asphalt (WMA) technologies have been widely developed and implemented over the past two decades.

WMA technologies allow the production and placement of asphalt mixtures at temperatures 20–40°C lower than those used for conventional HMA, while maintaining comparable mechanical and durability performance [2, 4]. Temperature reduction can be achieved through several approaches, including water-based foaming techniques, organic wax additives, and chemical surface-active additives [1]. This paper focuses on surfactant-based WMA systems, particularly their applicability with different binder types: conventional 50/70 penetration grade bitumen, rubber modified bitumen (RMB), and polymer-modified bitumen (PMB). Surface-active additives (surfactants) function by altering the interfacial energy relationships between bitumen and mineral aggregates. By reducing surface tension and improving coating behavior, they enhance aggregate coating efficiency and reduce internal friction within the mixture, thus improving workability and compactability at lower temperatures [3].

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Typical dosage rates range between 0.2–0.5% by weight of binder. For conventional 50/70 penetration grade bitumen, mixing temperatures may be reduced to approximately 140–150°C, while maintaining adequate volumetric and mechanical properties [2]. In the case of conventional 50/70 bitumen, reduced production temperatures also decrease oxidative aging during mixing, which may positively influence long-term cracking resistance [3]. Nevertheless, moisture susceptibility must be carefully evaluated, as lower production temperatures may affect aggregate drying efficiency and binder–aggregate adhesion [4].

When applied to crumb rubber modified binders, WMA technology can provide additional benefits. Rubber-modified binders typically exhibit higher viscosity, which traditionally requires elevated mixing temperatures. The use of surfactant additives enables lower processing temperatures, reducing emissions, limiting thermal degradation, and improving working conditions [2]. Similarly, polymer-modified bitumen (PMB) binders benefit from reduced thermal exposure, as excessive heating may lead to polymer degradation and loss of elastomeric properties [5]. Lower-temperature processing can therefore contribute to preserving the structural integrity of the polymer network. The environmental advantages of WMA technologies are well documented. Energy savings of 10–30% at the asphalt plant have been reported, alongside reductions in CO_2 emissions and improved occupational health conditions due to decreased fume generation [1, 2]. The objective of this study is to investigate the performance of surfactant-based WMA systems using conventional 50/70 bitumen, crumb rubber modified bitumen, and polymer-modified bitumen, with particular emphasis on rheological behaviors, compactability, and long-term performance characteristics.

2 Laboratory tests of moderately warm asphalt mixtures using different binders

2.1 Binders used in the tests

In 2025, the Department of Highway and Railway Engineering of the Budapest University of Technology and Economics (BME) carried out a mechanical examination of several AC 16 binder course asphalt mixtures made with rubber bitumen (RMB), polymer-modified bitumen (PMB) and normal B50/70 bitumen, which mixtures were made with a surface activating additive at a lower production temperature. At every case mix of dolomite and limestone were used as aggregate AC 16 asphalt mixes and their characteristics are given in table 1. The binder content was 4.6%, the surface activating additive was 0. 5% in all asphalt mixtures.

Table 1 Binder used in AC16 asphalt mixtures

Type	Marking (MOL)	Nomination (BME)	Incorporation mark.	Other
RMB 45/80-55	7-2097-B/24	A	180°C	Reference
PMB 25/55-65	7-2001-B/23	B	180°C	Reference
RMB 45/80-55 + WMA 3	7-2103-B/24	C’	140°C	
RMB 45/80-55 + WMA 2	7-2105-B/24	D’	140°C	
B 50/70	7-2129-B/24	L	180°C	Reference
B 50/70	7-2129-B/24	M	130°C	Reference
B 50/70 + WMA 3	7-2005-B/25	N	130°C	
B 50/70 + WMA 2	7-2006-B/25	P	130°C	
RMB 45/80-55	7-2097-B/24	K’	140°C	Reference

Asphalt mixtures were made according to MSZ EN 12697-35:2016 standard, while MSZ EN 12697-30:2019 and MSZ EN 12697-33:2019+A1:2023 standards were used for cylindrical and slab specimens, respectively, on temperatures shown in table 1. During the laboratory tests, the volumetric characteristics of the different mixtures were first determined (MSZ EN 12697-5; -6; -8), followed by stiffness tests on cylindrical test specimens (MSZ EN 12697-26), wheel track tests on slab specimens (MSZ EN 12697-22), water sensitivity tests on cylindrical specimens (MSZ EN 12697-12), and compressibility tests on cylindrical specimens (MSZ EN 12697-10) [6].

2.2 Air void content characteristics

When examining the void characteristics of an asphalt mixture, the first step is to determine the bulk density, then the maximum density, and from these the air void content of the mixture. Due to the limitations of the scope of this document, the results of the air void content that contains the most information for us are described below. The air void content of each mixture was determined from the bulk density and maximum density values based on MSZ EN 12697-8:2003 (withdrawn standard) according to the following formula:

$$V_m = (\rho_{max} - \rho_{bulk})/\rho_{max}) \cdot 100 \tag{1}$$

where:

V_m [%] – air void content of each mixture

ρ_{max} [Mg/m^3] – maximum density of each mixture

ρ_{bulk} [Mg/m^3] – bulk density of each mixture.

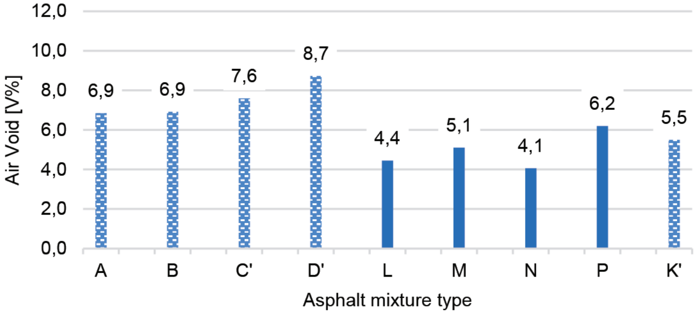

Figure 1 The results of the air void content of the individual asphalt mixtures [6]

The results obtained are depicted in figure 1. In general, it can be said that the air void content of mixtures made with conventional B 50/70 bitumen – except for the P mixture – is lower, i.e. more favorable than the air void content of mixtures made with polymer or rubber bitumen.

2.3 Stiffness

Marshall-compacted cylindrical specimens were prepared and used for stiffness modulus testing of the asphalt mixtures. These were produced in accordance with the MSZ EN 12697-30:2019 standard using a Marshall rammer with 2 x 50 strokes at table 1. Stiffness tests were carried out according to MSZ EN 12697-26:2018+A1:2023 standard (Annex C), at 20C°. The force is drawn by the test equipment to achieve a target load time of 124 msec and a specific elongation of 5 microstrains.

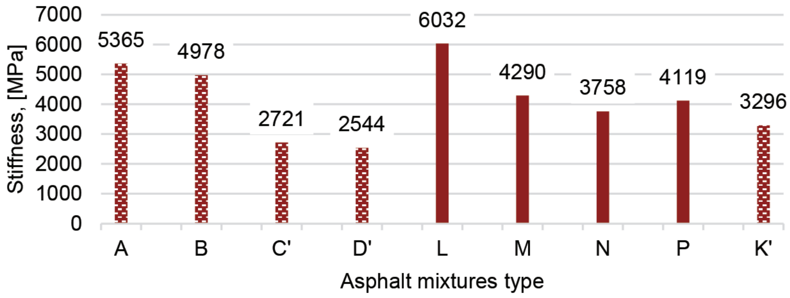

Figure 2 Results of the stiffness test (IT-CY) of certain asphalt mixtures [6]

The results obtained are summarized in figure 2. In general, in the case of standard mixtures processed at 180°C, the stiffness of the mixture made with B 50/70 road construction bitumen exceeded the value of mixtures made with polymer and rubber bitumen. As expected, lower stiffness values were obtained for the mixtures produced at 130°C. Even at this lower temperature, the mixture prepared with B 50/70 bitumen showed higher stiffness than the reference mixture produced with polymer-modified bitumen. The use of WMA additives resulted in much lower values than the benchmarks in the case of mixtures made with B 50/70 bitumen and polymer bitumen, and the value of the mixture made with B 50/70 bitumen exceeded the value of mixtures made with polymer bitumen in this case as well. The results of the stiffness test are illustrated in figure 2.

2.4 Wheel tracking behavior

The resistance to deformation caused by vehicle traffic and high temperatures, i.e. the wheel tracking test, was carried out in accordance with point 9.3.2 of the withdrawn standard MSZ EN 12697-22:2020 on the specimens cut to size. The test was carried out at 60°C, with 10000-wheel tracking and a load force of 700 N.

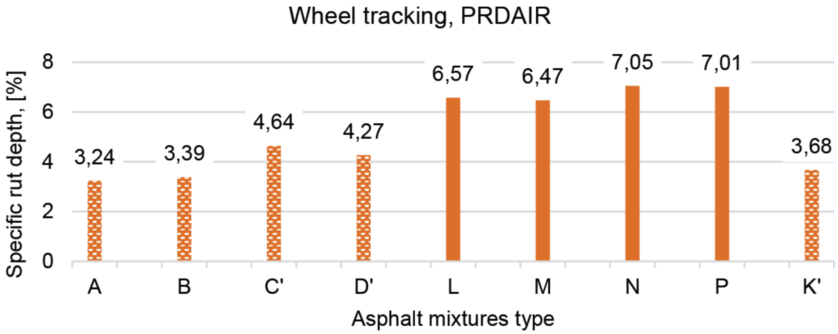

Figure 3 Results of the wheel tracking test of certain asphalt mixtures [6]

The results, i.e. the relative specific wheel track depth values of each mixture, are illustrated in figure 3. In general, the values of mixtures made with polymer and rubber bitumen were lower for both standards and mixtures containing additives, so they were more favorable than the values of mixtures made with B 50/70 road construction bitumen.

2.5 Water sensitivity

The water sensitivity test was performed according to the MSZ EN 12697-12:2018 point “A” method (ITSR) on a cylindrical test specimen. The tested parameter shows the ratio of the average split-tensile strength of 3 specimens of the same mixture stored in water at 40°C for 3 days to 3 reference specimens stored in dry at laboratory temperature, expressed as a percentage.

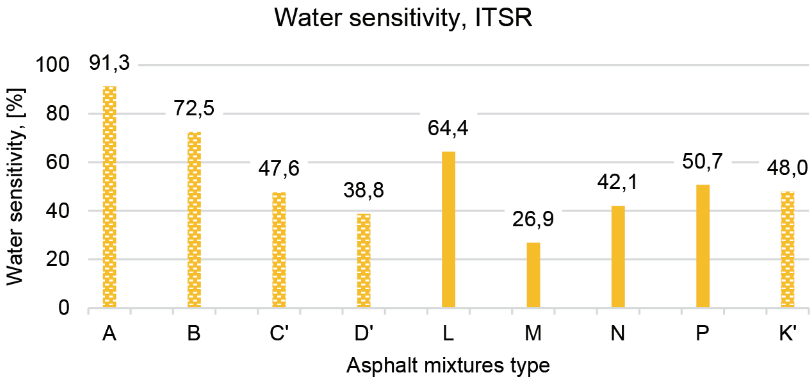

Figure 4 Results of the water sensitivity test of individual mixtures [6]

The water sensitivity test results are illustrated in figure 4. In general, it can be said that in the case of mixtures made with polymer and rubber bitumen as well as mixtures made with B 50/70 road construction bitumen, the values of the standard mixtures produced at 180°C were the most favorable, and the reduction of the incorporation temperature resulted in very unfavorable water sensitivity resistance values in the individual mixtures, even with the use of additives. Interestingly, the magnitude of the values of the additive mixtures was similar for all types of bitumen.

2.6 Compression

The cylindrical Marshall specimens required to measure the compressibility of each mixture were produced in accordance with the MSZ EN 12697-30:2019 standard, using a Marshall rammer, with 2 x 100 strokes, at the temperature indicated in table 1. The compressibility test was carried out in accordance with point 6.1.2 of the MSZ EN 12697-10:2018 standard, on a cylindrical test specimen. The examined parameter shows the amount of compaction energy (unit) required to compact a given mixture, i.e. the resistance of the material to compaction at a given temperature. Figure 5 illustrates the results obtained, where it can be said that the values of all polymer and rubber bitumen mixtures were lower, i.e. more favorable than the results of the mixtures made with B 50/70 road construction bitumen.

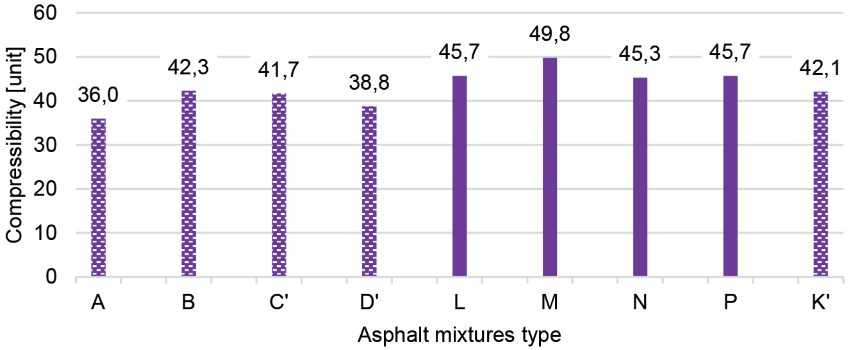

Figure 5 Results of the compressibility test of individual mixtures [6]

3 Conclusion

The results of each of the nine different AC 16 binding asphalt mixtures were summarized on a scale of 1 to 10, with 1 being the most favorable and 10 the least favorable; these results are presented in table 2. Overall, it can be noted that in the case of wheel tracking and compressibility tests, mixtures made with polymer and rubber bitumen performed better than mixtures made with B 50/70 road construction bitumen. At the same time, in the case of bulk density and therefore air void content tests, the latter performed better, except for a certain exceptionally well-performing K' mixture. In the case of stiffness and water sensitivity, such a sharp boundary cannot be established between the results of different materials made with bitumen. But another note is that the use of substances containing surfactants reduce the stiffness of individual mixtures. The results of the above tests further indicate that, although different surfactant additives were applied in the mixtures, the mechanical properties of the asphalt mixtures generally decrease because of the lower production temperature.

Table 2 Each mixture according to their test results, sorted from 1 (most favorable) to 10 (least favorable)

	Bulk density [Mg/cm³]	Maximum density [Mg/cm³]	Air Voids [%]	Stiffness (IT-CY) [MPa]	Wheel Tracking [%]	Water density (ITSR) [%]	Compression [unit]
1	L	D'	N	L	A	A	A
2	K'	B	L	A	B	B	D'
3	M	P	M	B	K'	L	C'
4	P	K'	K'	M	D'	P	K'
5	N	A	P	P	C'	K'	B
6	B	C'	A	N	M	C'	N
7	A	M	B	K'	L	N	L
8	C'	L	C'	C'	P	D'	P
9	D'	N	D'	D'	N	M	M

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